MODULATED PULSE LIDAR

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LONG TERM GOAL

The goal of this project is to improve the performance of lidar systems for multi-mission use. Specifically, we will study the application of radar and acoustic modulation, detection, and signal processing techniques to lidar systems. A modulated pulse lidar system will be developed and experimental demonstration results will be compared to Monte Carlo modeling predictions. This technique is also applicable to underwater, atmospheric and biological tissue imaging and detection systems.

SCIENTIFIC OBJECTIVES

The primary objectives to be addressed under this task are the following: (1)Enhance the contrast of underwater objects by use of a modulated pulse lidar system. For this technology program, a multi-modulation frequency transmitter and wide bandwidth, large area optical detector will be developed. (2)Evaluate experimentally the effectiveness of this technique as a function of target characteristics (hard, soft), water properties (clarity, depth), lidar system parameters (receiver field of view, transmitter beam divergence, altitude), and environmental factors (sea surface variations, background sunlight). (3)Develop a theoretical model to obtain better insight into the physics of the problem and predict the experimental results.

APPROACH

In December, 1995, a modulated pulse lidar system was fielded at the Atlantic Undersea Test and Evaluation Center (AUTEC). The field test results established the benefits of the modulated pulse system in improving the contrast of small, shallow underwater targets which remain contrast limited in conventional lidar systems [1, 2]. Since the feasibility of the modulated pulse lidar system was established, the next task and the focus of this program is to optimize the system for multi-mission use by developing a multiple modulation frequency system. In FY97, a multiple modulation frequency optical transmitter was designed and developed [3, 4]. The next step is to use this transmitter to

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determine effect of optical scattering on the modulated pulse, to identify system and environmental parameters which affect the ocean water frequency spectra, and to validate Monte Carlo simulations (developed under ILIR funding) for predicting ocean water frequency spectra measurements. This data will be used to better characterize water optical properties and to determine the modulation frequency which maximizes target contrast for a given set of conditions (i.e., water quality, target characteristics).

WORK COMPLETED

An ocean experiment to demonstrate the ability of modulated pulse lidar to improve target contrast was completed in FY96. An improved multiple frequency transmitter for 532 and 1064 nm was developed. A 3-5 GHz large area detector was developed. The forward propagation Monte Carlo model was completed.

TECHNICAL RESULTS

The most significant result from the ocean experiment is shown in Fig. 1. Here, the target return signals from both the modulated pulse lidar and the conventional, unmodulated lidar are displayed. This figure clearly demonstrates that the contrast of the modulated pulse target return is improved relative to the lidar return. This contrast enhancement is credited to the reduction in microwave backscatter (at least 10 dB) achieved with the new detection scheme.

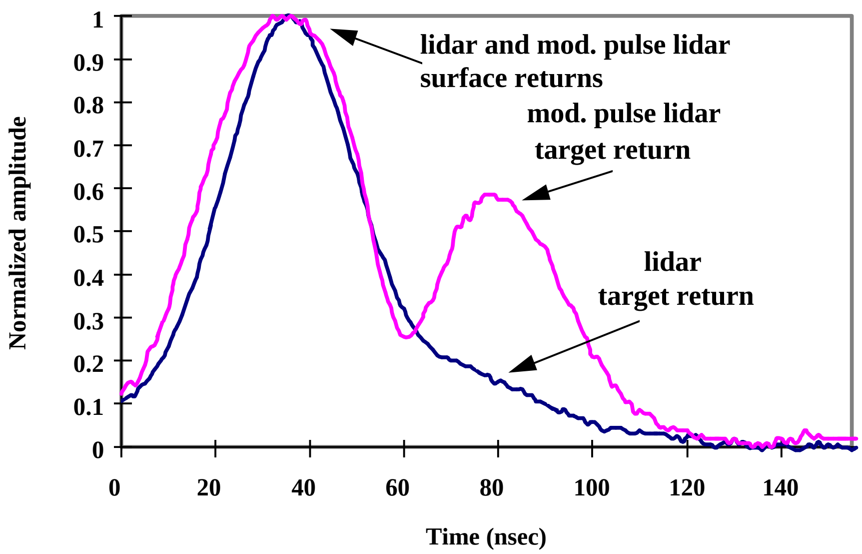

Fig. 1. Lidar and modulated pulse lidar echo returns obtained with the following set of parameters: 0.15 m target at 5 m depth, wide beam divergence (40 milliradians), and narrow field of view (10 milliradians). The contrast of the modulated pulse lidar target return is improved relative to that of the lidar return due to the backscatter clutter reduction.

The goal of FY97 was to develop a multiple modulation frequency system to measure water and target frequency spectra. This led to the investigation of techniques for producing a multiple frequency (0.5- 10 GHz), high optical power (>10 kW), pulsed (10-

15 nsec), blue-green (532 nm) optical transmitter. The results of this study showed that the harmonic content present in a mode-locked pulse train can produce these transmitter characteristics. By phase-locking the oscillating modes of a laser cavity, a train of short, high-power pulses are produced. In the frequency domain, this corresponds to a discrete set of frequencies which can be tailored by appropriate choice of modulating frequency. In addition, the high peak power of the mode-locked transmitter improves the doubling efficiency for generation of blue-green radiation. For this application, active mode-locking of a Nd:YAG oscillator was achieved through the combination of a dye sheet and an intracavity 500 MHz electro-optic phase modulator. The dye sheet both Q-switches the laser output and enhances the active modulation because of the saturable absorber fast relaxation time (<300 psec). The constructed transmitter produced a 10 nsec train of 100 psec pulses separated by the 2 nsec modulation period. A sample of the laser output detected by a 1 GHz photodetector is shown in Fig. 2. Frequency harmonics up to 10 GHz were observed when the laser output was detected by a high-speed streak camera.

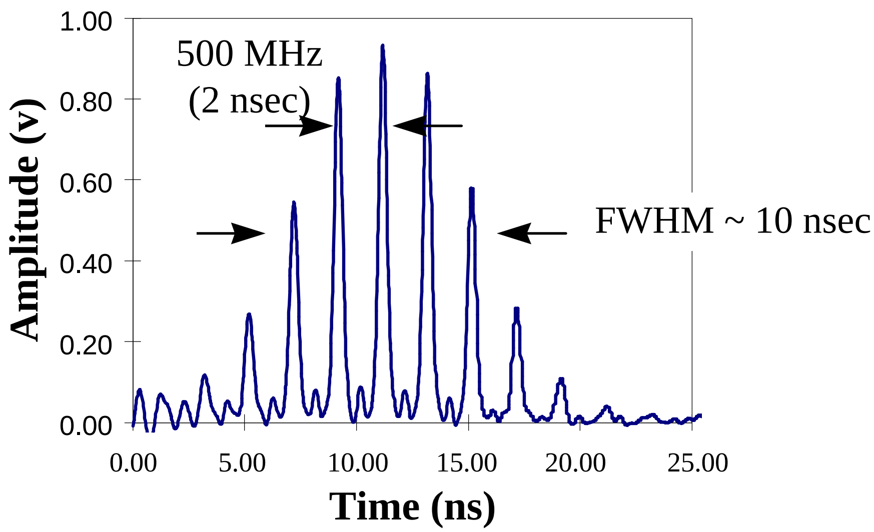

Fig. 2. Sample of the Q-switched, mode-locked output from the modulated optical transmitter.

IMPACT/APPLICATION

The modulated pulse lidar system has the potential to improve the lidar system search rate by a factor of 10 to 100 for airborne ASW and mine localization lidar. For an underwater system such as a line scanner, the performance improvements will include high resolution depth imagining and contrast enhancement of the same order. Similar improvements are anticipated for underwater ocean optical scattering layer mapping or biological tissue imaging applications. The multiple modulation frequency system will permit optimized target detection and classification and enhanced system capability in water clarity assessments. In addition, other systems can benefit from the technology developed in the modulated pulse lidar project, including atmospheric lidar.

The technology developed under this program can be used to improve existing Navy and commercial lidar systems. The military systems include 1) Mine detection Line scanner, 2) Owl, 3) the US Army SHOALS system, 4) DMA bottom mapping system, and 5) several classified prototype systems. A number of bottom mapping systems will also directly benefit, including the Australian, Canadian, and Swedish systems.

TRANSITIONS

At the completion of FY '97, a multiple frequency modulated (0.5 –10 GHz), blue-green, high-power transmitter was designed, developed, and tested. In addition a wideband (>3 GHz), high Quantum Efficiency (>35%), low noise (1.1 N.F.), large area (8mm diameter.) blue/green was developed. The detector is commercially available from Intevac in San Jose, Ca. These components can be transitioned into any system which requires both high-speed modulation and a corresponding large bandwidth detector (i.e., biomedical applications, communications).

The modeling efforts will result in an approach for predicting future experimental results for the modulated pulse lidar detection scheme. At the end of the program, several optimized modulated pulse lidar systems will be designed and performance predictions will be calculated for possible transitions. Candidate transitions include mine detection line scanner, undersea layer imaging, airborne mine and optical scattering layer detection lidar, laser bathymetry lidar with small hazard detection capability, and biological tissue imaging system.

RELATED PROJECTS

Several programs have resulted from the work accomplished on this project. These programs will continue to be run or monitored through NAWCADPAX.

1. An internal research project for development of a very high speed (10 GHz bandwidth) detector was initiated.
2. An internal research project for development of a Monte Carlo model to predict modulated pulse lidar measurements has received continued funding for FY98.
3. Four SBIR phase one topics were initiated (two proposals in each topic were funded): 1) Development of large area ultra high speed photo detectors, 2) High speed optical modulator for high capacity systems, 3) Improved method of measuring Ocean optical characteristics, and 4) Development of a 532 nm narrowband optical filter.

The research of 4 PhD students in Electrophysics have been supported directly by this project. Two graduated in FY96, the third in FY97, and the fourth is expected to graduate in FY98.

PUBLICATIONS (FY97)

1. L. Mullen, V. M. Contarino, "Modulated Pulse Lidar for Enhanced Underwater *Proceedings of Ocean Optics X111, SPIE Volume 2963*, Halifax, Nova Scotia, Canada, October 22-25, 1996, pp. 731-736.

2. L. Mullen, V. M. Contarino, P. R. Herczfeld, “Hybrid Lidar-Radar Ocean *IEEE Transactions on Microwave Theory and Techniques*, Vol. 44, no. 12, December, 1996, pp. 2703-2710.
3. L. Mullen, V. M. Contarino, P. R. Herczfeld, “Intracavity Phase Modulated Transmitter for Hybrid Lidar-Radar,” *Optics & Photonics News*, Vol. 7, no. 12, December, 1996, pp. 42-43.
4. L. Mullen, V. M. Contarino, “Multiple frequency modulated pulse lidar system,” *Proceedings of the 1997 Conference on Lasers and Electro-optics*, Baltimore, MD, May 18-23, 1997, p. 279.

PATENTS

pending patent application - L. Mullen, V. M. Contarino, P. R. Herczfeld, *Modulated Lidar System*, Case #77098